Identifying hotspots areas for chloride inputs to nearshore surface waters in the western Lake Ontario basin via direct groundwater discharge

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1. Introduction

- Large volumes of road salt (11.5 tonnes) are applied annually per kilometer of road in Ontario (ECCC, 2021), with over half of this salt infiltrating into groundwater (Van Meter et al., 2019).
- Cl concentrations in Great Lakes have been increasing over last decade (ORMGP, 2022).
- Groundwater salt contamination represents a long-term legacy challenge for lake water quality due to accumulation of salt in urban aquifers.
- Groundwater may be important year-round pathway delivering road salt (chloride [Cl]) to the Great Lakes, but the contribution of this pathway is unclear.

Objective:

- Identify 'hotspot' areas where direct groundwater discharge may be delivering high Cl loads to nearshore waters of western Lake Ontario.

2. Methodology

Geophysical Imaging

- Electromagnetic induction (EMI) surveys conducted as a rapid screening tool to identify sites with potentially high subsurface salt concentrations (Figure 1a; blue markers). CMD Explorer (GF Instruments, Czechia) used to measure apparent electrical conductivity (EC) at six depths (Figure 1b).
- Sites identified with high apparent EC (and potentially high Cl) were then surveyed via electrical resistivity tomography (ERT). Syscal Pro Switch 48 resistivity unit (Iris Instruments, France) used to measure apparent electrical resistivity distributions (reciprocal of EC; Figure 1c).

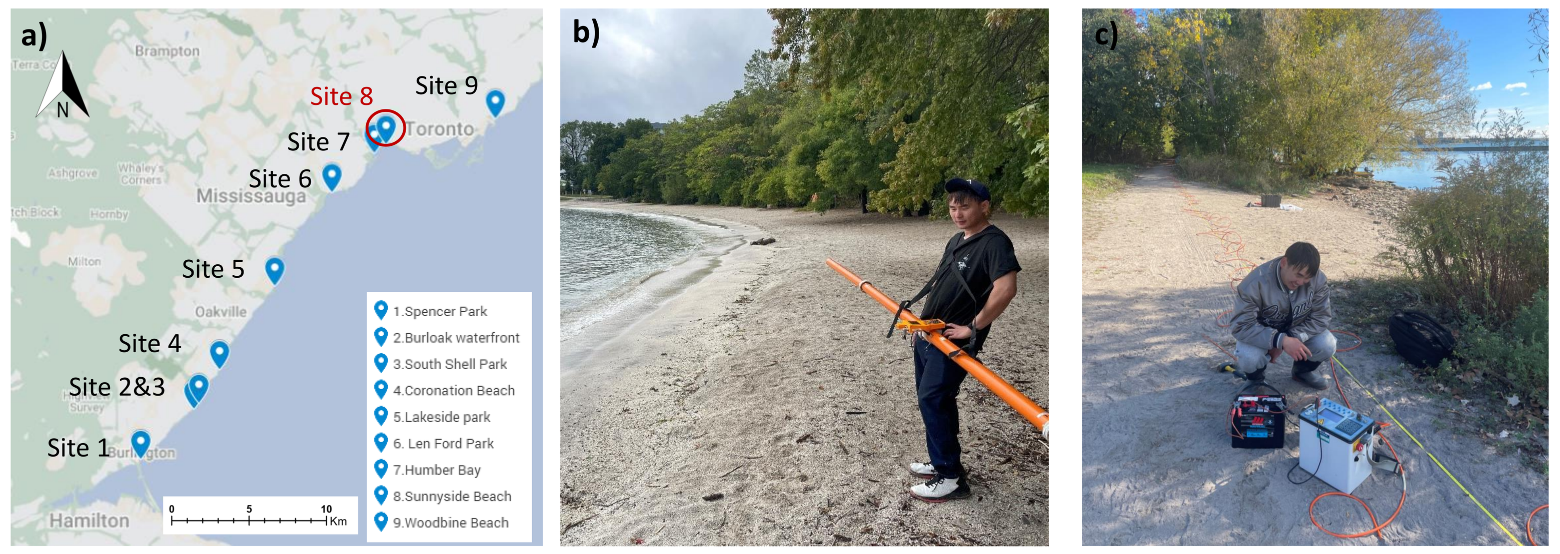

Figure 1: (a) Aerial map of sites surveyed, (b) EMI surveying, and (c) ERT surveying at Site 8.

Shallow Groundwater Sampling

- Shallow groundwater samples collected at select locations via drive-point piezometers with samples analyzed for water EC and Cl^- concentrations. Sampling enabled verification of EMI and ERT survey data (Figure 2).

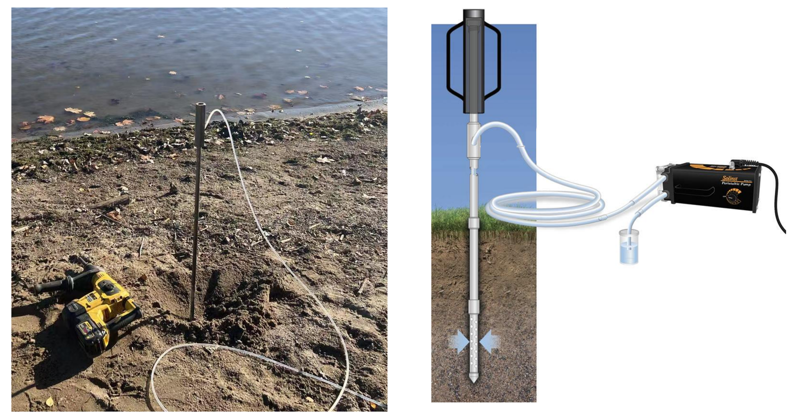

Figure 2: Shallow groundwater collection via drive-point piezometer, tubing, and peristaltic pump.

Radon-222 (^{222}Rn) Surveys

- ^{222}Rn is valuable tracer for groundwater discharge as ^{222}Rn concentrations typically 2-3 orders of magnitude higher in groundwater than in surface water.
- Continuous measurement of offshore (50 to 200 m) ^{222}Rn (RAD7 unit; Durridge, USA) and EC will also be used to identify hotpots of groundwater discharge and chloride inputs.

Figure 3: Set-up of ^{222}Rn detector system

3. Preliminary Results

EMI and ERT Identification of Hotspots

- Maximum apparent EC based on EMI surveys varied between nine surveys sites with highest values observed at Site 8 (Sunnyside Beach; Table 1).
- Apparent EC varied along EMI survey lines and with depth below ground surface with results for Site 8 shown in Figure 4. Dominant soil types at Site 8 are sand and silt (based on borehole logs provided by Oak Ridges Moraine Groundwater Program).

Table 1: Maximum apparent EC measured at 9 sites using EMI.

Site Number	1	2	3	4	5	6	7	8	9
Survey Length (m)	320	300	350	680	810	1400	880	2720	1600
Maximum EC (mS/m)	73	26	50	67	40	47	55	88	25

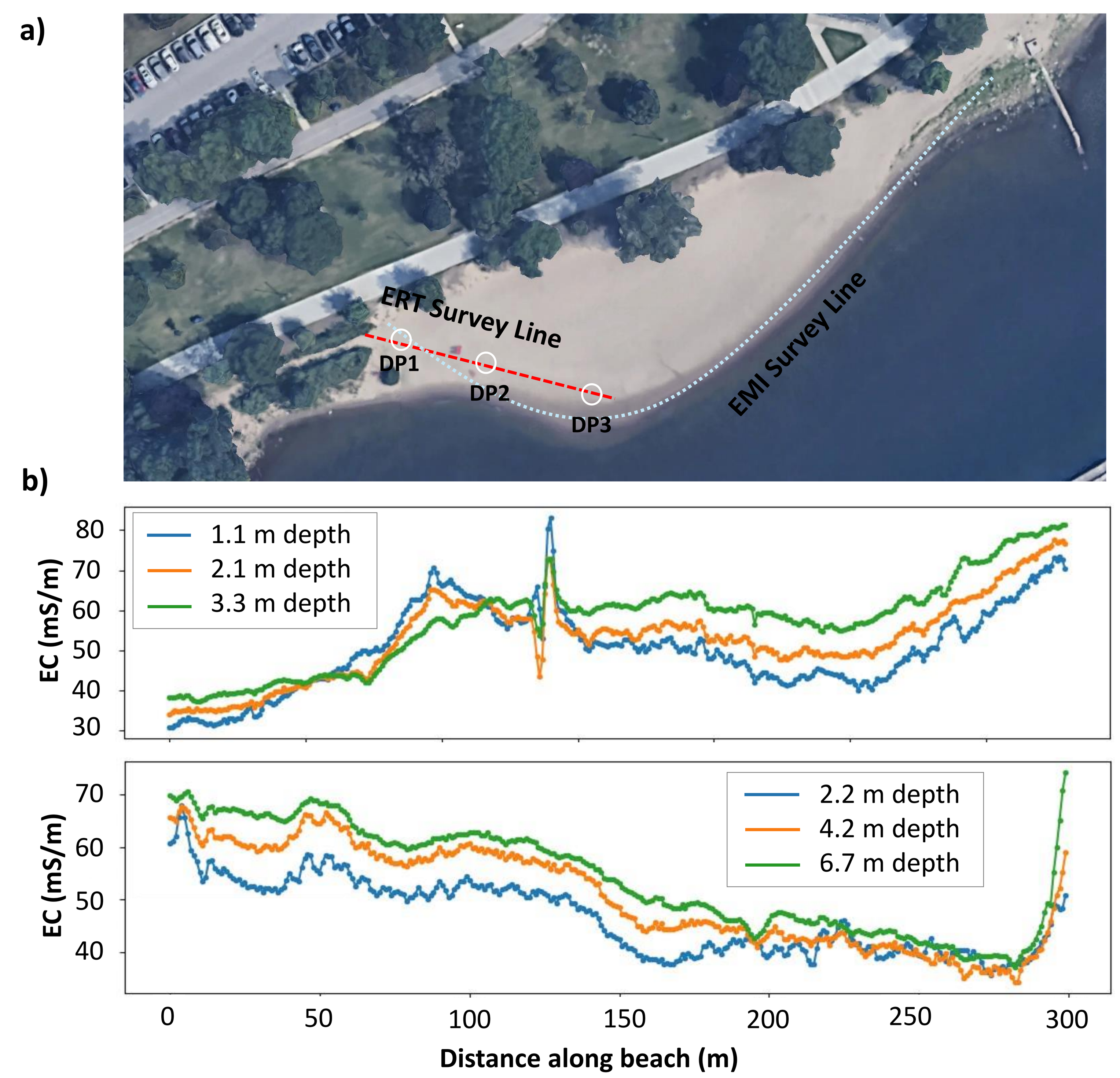

Figure 4: (a) Aerial map of Sunnyside Beach (Site 8) indicating EMI and ERT survey lines and location of drive-point sampling, and (b) apparent EC data collected via EMI survey.

- Using Archie's Law, bulk conductivity values exceeding 48 mS/m from EMI imaging indicate that porewater Cl^- concentrations may exceed CCME acute guideline of 640 mg/L.
- Figure 5 show cross-section of electrical resistivity along survey line marked in Figure 4a.
- Upper 0.5-1.0 m of subsurface exhibit high resistivity, which is likely due to unsaturated sand layer.
- Deeper subsurface (1-6 m) shows very low resistivity (i.e., high EC), which may be due to high porewater Cl concentrations.
- Resistivity increases at > 6 m, which may be due to lower porosity bedrock.

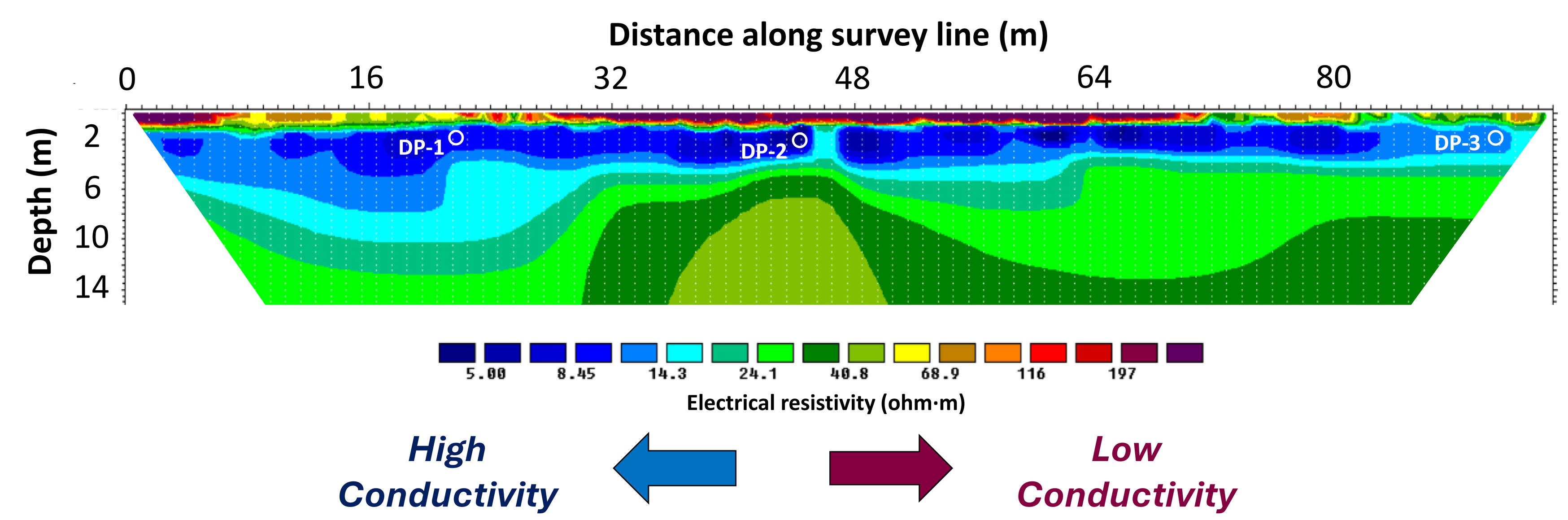

Figure 5: Cross-sectional image of electrical resistivity measured at Sunnyside Beach (Site 8).

Shallow Groundwater Quality

- Cl concentrations in shallow groundwater at Site 8 (>1500 mg/L) greatly exceed concentrations in Lake Ontario (~50 mg/L, based on Ontario MECP surface water quality data; Figure 6).
- Drive point sampling data indicate that high apparent EC observed in EMI and ERT data at Site 8 may be associated with high Cl concentrations.

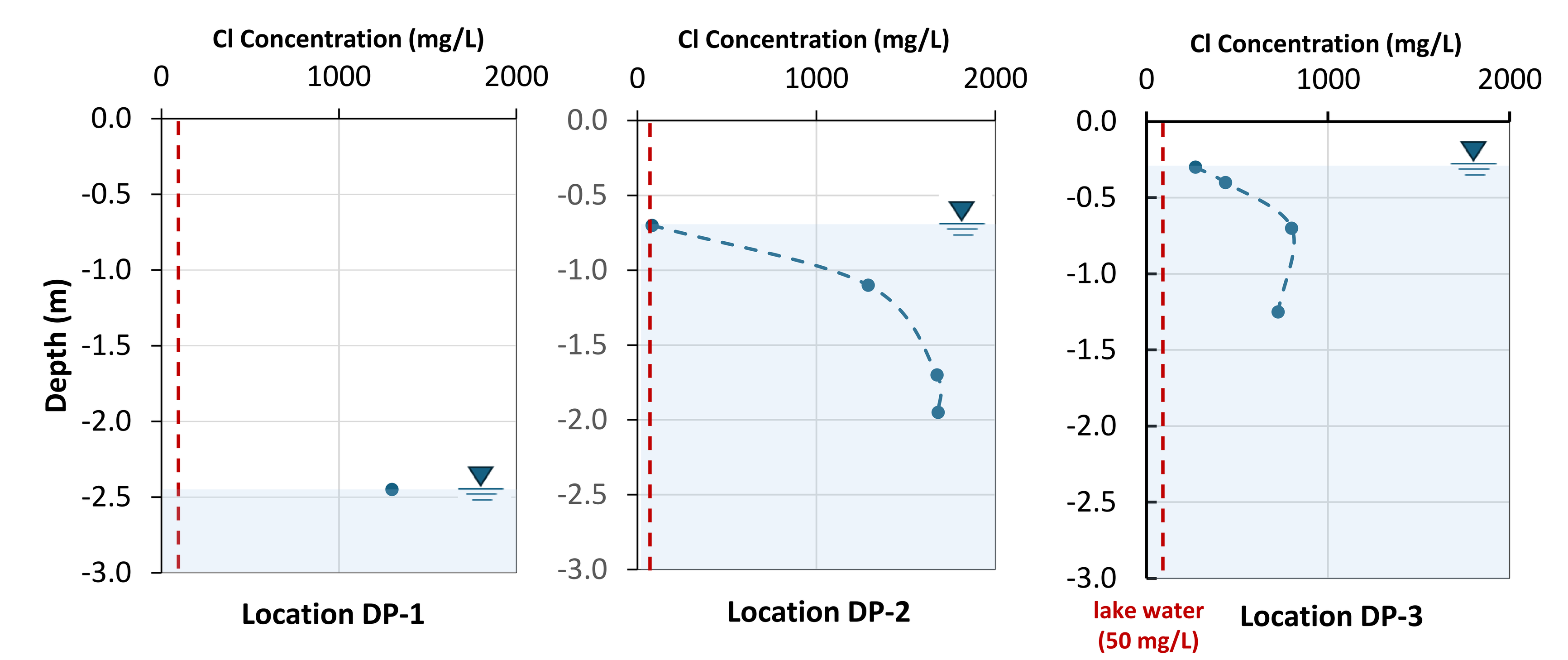

Figure 6: Chloride concentration measured at multiple depths at drive-point sampling locations at Sunnyside Beach (Site 8).

5. Ongoing and Future Work

- Conduct more extensive EMI surveys at select 'hotspot' sites to produce three-dimensional (3D) images of apparent EC. 3D ERT surveys will also be conducted to provide 3D continuous information on groundwater Cl contamination.
- More extensive verification of ERT images using drive-point and multi-level samplers.
- Time-lapse ERT and temporal drive-point sampling to assess seasonal variability in groundwater Cl.
- Estimate localized direct groundwater discharge to lake at 'hotspot' sites (e.g., mini-piezometers).
- Estimate direct groundwater discharge along shoreline with continuous Rn-222 surveys.

References

Adyasari, D., Dimova, N.T., Dulai, H., Gilfedder, B.S., Cartwright, I., McKenzie, T., Fuleky, P. (2023) Radon-222 as a groundwater discharge tracer to surface waters. Earth-Science Reviews, 238, 104321.

Harvey, F.E., Rudolph, D.L., Frape, S.K. (2000) Estimating ground water flux into large lakes: Application in the Hamilton Harbor, Western Lake Ontario. Ground Water, 38(4), 550-565.

Van Meter, K.J., Chowdhury, S., Byrnes, D.K., Basu, N.B. (2019) Biogeochemical asynchrony: ecosystem drivers of seasonal concentration regimes across the Great Lakes Basin. Limnology and Oceanography, 65(4), 848-862.

Oak Ridges Moraine Groundwater Program (ORMGP) (2022) Estimation of direct groundwater discharge and salt (NaCl) loading to the north shore of Lake Ontario. Retrieved from https://www.oakridgeswater.ca

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Oak Ridges Moraine Groundwater Program

Ontario Ministry of the Environment, Conservation and Parks